Population synthesis of common-envelope mergers on the giant branches

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Stellar mergers

Occurrence:

- Collisions: $\tau \sim \mathrm{day}$? (Sills et al. 2001)
- Binary mergers: convective envelope: $\tau \sim \tau_{\mathrm{dyn}}; \mathrm{yr} - \mathrm{kyr}$?
- Binary mergers: radiative envelope: $\tau \sim \tau_{\mathrm{th}} \rightarrow \tau_{\mathrm{dyn}}$

HST

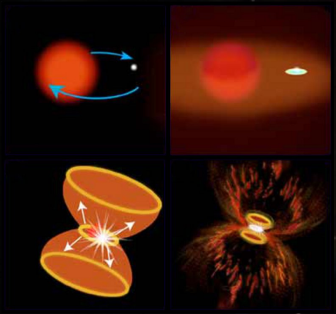
NOAO/AURA/NSF

- A significant fraction of stars ($\sim$ 10%?) may be involved in mergers
- Luminous red novae?
- V 838 Mon?

Merger products

Physics:

- **Angular momentum !**
- Rapid, differential rotation
- Enhanced mixing
- Magnetic fields
- **Enhanced mass loss**



HST

Observability:

- Rapid rotation?
- Abundance anomalies?
- Circumstellar material
- Blue stragglers
- “Weird binaries”

Input models

Stellar-evolution code `ev` (Eggleton, 1971,2, etc.):

- 116 single-star models: 0.5 – 20.0 $M_\odot$ (primary, remnant)
- 28 brown-dwarf models: 0.01 – 0.60 $M_\odot$ (secondary)
- Solar composition; X=0.70, Y=0.28, Z=0.02

- Core mass: $M_\mathrm{c} \equiv$ central region where $X < 0.1$
- Envelope binding energy: $E_\mathrm{bind} \equiv \int_{M_\mathrm{c}}^{M_\mathrm{s}} \left(E_\mathrm{int}(m) - \frac{Gm}{r(m)} \right) \mathrm{d}m$

Binary evolution

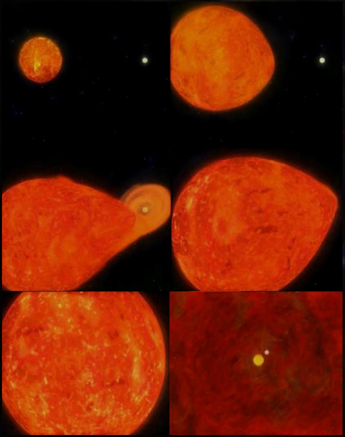
Stars

- Constant star-formation rate
- Randomly select 10^7 binaries:
  - $M_{\rm p}$: Miller-Scalo IMF
  - $q \equiv M_{\rm s}/M_{\rm p}$: $g(q)\,{\rm d}q = \{q^{-0.9}, 1, q\}\ {\rm d}q$
- Follow the evolution of track closest in mass to primary
- When mass comes closer to next track, jump with conservation of $M_{\rm c}$

Orbit

- Assume synchronous rotation on RGB, AGB: $\omega_{\rm p} = \omega_{\rm orb}$
- Mass and AM loss from stellar wind
- Redistribute AM, so that $J_{\rm tot} = (I_{\rm p} + I_{\rm orb})\,\omega_{\rm orb}$
- If $v_{\rm rot} > v_{\rm crit}$: lose additional mass and AM until $v_{\rm rot} \leq v_{\rm crit}$
- $v_{\rm crit} \equiv \{0.1, 1/3, 1.0\}\ v_{\rm br}$

Common envelope and spiral-in



- CE occurs when:
  - $R_\mathrm{p} > R_\mathrm{RL,p}$ and $q > q_\mathrm{crit}(M_\mathrm{p}, M_\mathrm{c})$ (Hurley et al. 2002)
  - $J_\mathrm{prim} > \frac{1}{3} J_\mathrm{orb}$ (Darwin 1879)
- Classical energy formalism to determine post-CE orbit (Webbink 1984):

$$E_\mathrm{bind} = \alpha_\mathrm{CE} \left(\frac{G M_\mathrm{p} M_\mathrm{s}}{2\, a_\mathrm{i}} - \frac{G M_\mathrm{c} M_\mathrm{s}}{2\, a_\mathrm{f}} \right)$$

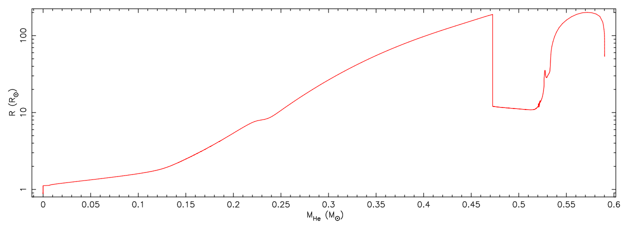
- $\alpha_\mathrm{CE} = \{0.1, 0.5, 1.0\}$
- Merger occurs if after CE: $R_\mathrm{RL,s} < R_\mathrm{s}$

Evolution of the merger product

After the merger:

- the merger product evolves mostly in the same way as a normal single star
- difference: $v_{\rm rot}$, hence $\dot{M}$

- whenever $v_{\rm rot} \geq v_{\rm crit}$, the star undergoes enhanced mass loss, to ensure that it remains spinning sub-critically
  - this is especially important around core helium ignition

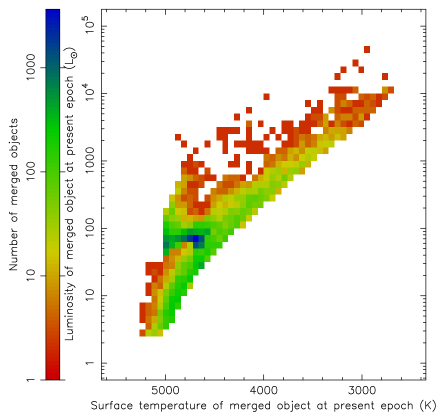


Population-synthesis results

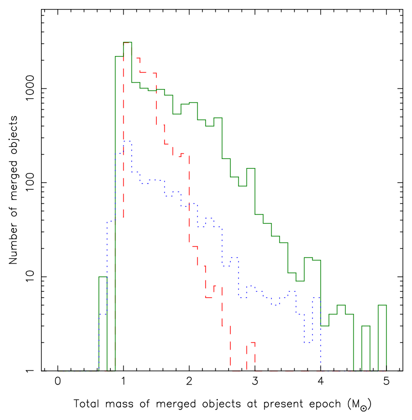
	Number	Fraction of previous group	Fraction of initial population
Total binary population:	**10,000,000**	**100%**	**100%**
No MT	7,094,523	71%	71%
Stable MT	1,267,854	13%	13%
Unstable MT:	**1,637,623**	**16%**	**16%**
CE Survivors:	789,807	48%	7.9%
Mergers:	**847,816**	**52%**	**8.5%**
Mergers due to RLOF	689,815	81%	6.9%
Mergers due to tidal capture	158,001	19%	1.6%
Mergers on RGB	738,385	87%	7.4%
Mergers on AGB	109,431	13%	1.1%
WDs	822,773	97%	8.2%
GB/HB stars:	**25,041**	**3%**	**0.25%**
RGB	**9,301**	**37%**	**0.09%**
HB	**14,305**	**57%**	**0.14%**
AGB	**1,435**	**6%**	**0.01%**
Critically rotating RGB stars	297	3.2%	0.003%
Critically rotating HB stars	4,504	31%	0.05%
Critically rotating AGB stars	1	0.1%	0.00001%

Merger population

HRD:



Total mass:

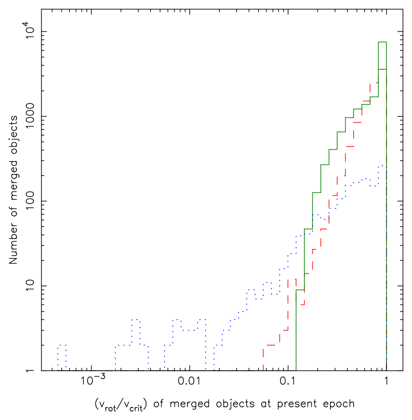


RGB **HB** **AGB**

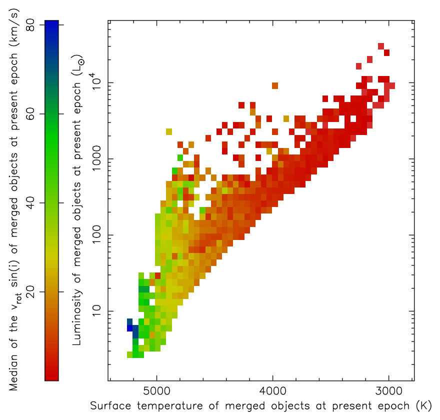
$$v_{\mathrm{crit}} = \frac{1}{3} v_{\mathrm{br}}$$

Rotational velocities

v_{rot}/v_{crit}:



$v_{rot}\sin i$ (km/s):

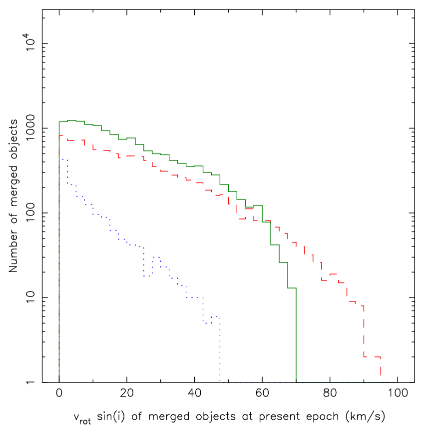


RGB HB AGB

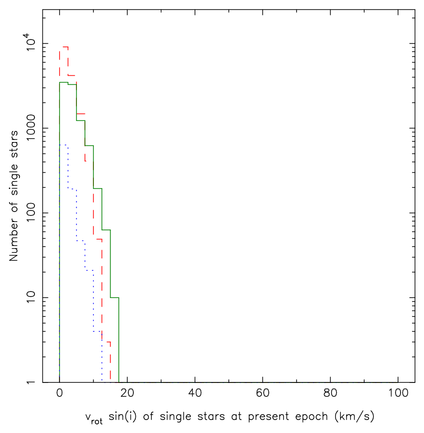
$$v_{crit} = \frac{1}{3} v_{br}$$

Comparison to single stars

Merger remnants:



Single stars:



RGB HB AGB

$$v_{crit} = \frac{1}{3} v_{br}$$

Comparison to single stars

Ev. phase	population	N	$\frac{N}{N_{tot}}$	M ($M_\odot$)	v sin i (km/s)	Fraction with $v_{rot} \leq 0.1\, v_{crit}$	Fraction with $v_{rot} = v_{crit}$
RGB	mergers	9301	0.37	1.20	18.4	(0.001)	0.0319
	single	178651	0.61	1.20	1.9	0.9627	0.000
HB	mergers	14305	0.57	1.35	16.1	(0.0000)	0.3149
	single	104979	0.36	1.58	3.2	0.0886	0.0021
AGB	mergers	1435	0.06	1.34	6.0	0.0683	(0.0007)
	single	10487	0.04	1.45	1.3	0.5657	(0.0000)
Total	mergers	25041	1.00	1.28	16.2	0.0043	0.1918
	single	294117	1.00	1.23	2.3	0.6366	0.0008

Critical rotational velocity

- The observed (projected) rotational velocity is roughly an order of magnitude larger for merger products
- Most merger products on the GBs have ignited helium, most normal single stars have not

Conclusions

Results:

- Common-envelope mergers on the giant branches lead to rapidly rotating merger products
- Merger products through this channel rotate roughly $10\times$ faster than normal single stars
- In a population with 50% initial binaries, $\sim 3.4\%$ of the single stars would be a GB merger remnant

Observables:

- Telltales of (former) rapid rotation may include abundance anomalies, small envelope mass, oblate stars, IR excess and asymmetric nebulae
- Single sdB stars?